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MEMORANDUM REPORT ARBRL-MR-02927

**THERMOMECHANICAL ANALYSIS OF TiO₂-WAX
BLEND USED IN WEAR-REDUCING LINERS**

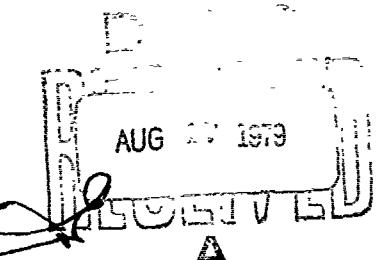
**Michael T. Mocella
J. Richard Ward**

June 1979



**US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND**

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) SRF Chamber residue collects in the 155-mm M185 howitzer after repeated firings of the zone 8S, XM203E1 charge, conditioned at 336K. The residue does not appear with charges conditioned at ambient temperatures. One hypothesis for the residue is that the TiO ₂ -wax blend softens and splatters on the chamber wall to which unburned fragments stick.		
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20. ABSTRACT: (Cont'd)

As part of the laboratory experiments run in conjunction with gun firing tests by the Large Caliber Weapons Systems Laboratory to isolate and eliminate the cause of residue, thermomechanical analysis was done on the TiO_2 /wax blend to see if the softening temperature was lowered under pressure. Without external pressure, the blend softened at 338K, near the 347K melting temperature of the wax which is also near the maximum conditioning temperature of 336K. Under external loading with a 100 gram mass, the softening temperature was reduced to 300K. These experiments suggest a wax melting above 380K may prove to be a remedy for the residue problem. Subsequent testing by the LCWSL showed that the residue was significantly reduced when a higher-melting wax was used in the TiO_2 -wax blend.

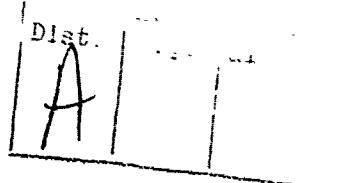
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I. INTRODUCTION

The standard wear-reducing liner in the U. S. ammunition inventory consists of titanium dioxide blended into paraffin wax. The blend is forty-five parts by weight TiO₂. The TiO₂-wax liner, invented in Sweden, replaced polyurethane foam, a Canadian invention, which was the first wear-reducing liner adopted by the U. S.¹

During development tests with the TiO₂-wax liner, it was noticed that the TiO₂-wax liner tended to leave residue in the chamber when the ammunition was conditioned above 325K (125°F). It was also noticed that the additive was not as effective in reducing erosion at the higher conditioning temperature.² The polyurethane foam, on the other hand, never left residue at any conditioning temperature.^{3,4}

More recently the TiO₂-wax liner conditioned at 336K seems to be the culprit in residue from the 155 mm M203E1 charge. This zone 8S propelling charge is currently being tested as a replacement for the M203 charge. The M203 charge is compatible with the 155 mm M199 cannon, but the charge cannot be safely fired from the 155 mm M185 cannon which has a shorter chamber than the M199 cannon. The M203E1 charge is shorter, and therefore fatter, than the M203 so it can be fired from both 155 mm howitzers.

During a safety test in which M203E1 charges conditioned at 336K (145°F) were being fired from the M199 cannon, residue was found in the chamber. Eventually, the residue collected to the point that a projectile failed to ram properly.

One hypothesis for the residue formation is that the wax softens at 336K, and a waxy residue is deposited on the chamber when 336K-conditioned charges are repeatedly fired. In addition, more unburned fragments may be left in the chamber at the higher conditioning temperature, thereby providing material to stick to the chamber wall. This seems consistent with the earlier observation that the TiO₂-wax liner does not perform as well in ammunition conditioned at higher temperatures.

¹A. C. Alkidas, M. Summerfield, and J. R. Ward, "A Survey of Wear-Reducing Additives and of the Mechanisms Proposed to Explain Their Wear-Reducing Action", BRL Memorandum Report No. 2603, March 1976. (AD #B010280L)

²R. P. Grepps, J. W. Harris, S. B. Parkoff, and G. Neegard, "Final Report of Product Improvement Test of Ammunition Additive Effect on M41 and M68 Gun Tube Life", DPS Report No. 1520, December 1964.

³P. R. Grepps, "Component Development Test of Laminar Coolant, Barrel Wear-Reducing Additive in Cartridge, 105 mm Gun, M68, Ammunition Components", DPS Report No. 708, January 1963.

⁴P. R. Grepps, "Development Tests of Laminar Cooling of Gun Bores, 90 mm, M41", DPS Report No. TW-417/6, June 1959.

To help test the hypothesis for the residue formation, and to suggest future tests, a thermomechanical analysis was made of the TiO_2 -wax blend to find the softening temperature.

II. EXPERIMENTAL

All thermal measurements were conducted with a DuPont 990 Thermal Analyzer. Thermal penetration measurements were made with a DuPont 942 Thermomechanical Analyzer; differential scanning calorimetry measurements were made with a DuPont Cell Base equipped with a Pressure DSC Cell.

Samples of the TiO_2 -wax wear reducing additive were prepared by slicing a section of the additive off of its cloth backing and filing the sample to get a smooth surface. The sample is approximately 2.5 mm thick. Samples of the polyurethane additive were cut directly from a sheet of approximately 3.1 mm thickness.

III. RESULTS

A comparison of the thermochemical behavior of TiO_2 -wax versus polyurethane by differential scanning calorimetry (DSC) reveals substantial differences between these two materials. The TiO_2 -wax blend showed an endotherm beginning at 318K (113°F); the endotherm reaches a maximum at the melting point of the wax, 347K (165°F). In contrast, the polyurethane shows no evidence of any endotherm until 553K (535°F); this endotherm peaks at 564K (555°F). At higher temperatures an exotherm presumed to be associated with decomposition of the sample occurs and reaches a maximum at 644K (700°F).

To determine the softening temperature, measurements were made of the penetration temperature of TiO_2 -wax samples under various external loads. The sample is heated at a programmed rate from ambient temperature. The sample expands in a manner determined by the coefficient of linear expansion. The external probe on the thermomechanical analyzer measures the length of the sample. When the sample softens, the external probe setting on the sample punches through the surface. The softening temperature then corresponds to the temperature where the sample stops expanding. A summary of the penetration temperature vs load is shown in Figure 1. Under no load, penetration is seen to occur only a few degrees below the melting point of the wax. However, under a moderate load of 10 grams, the penetration temperature drops approximately 40K below the melting point. This penetration temperature decreases only slightly upon further loading to the maximum load tested of 100 grams.

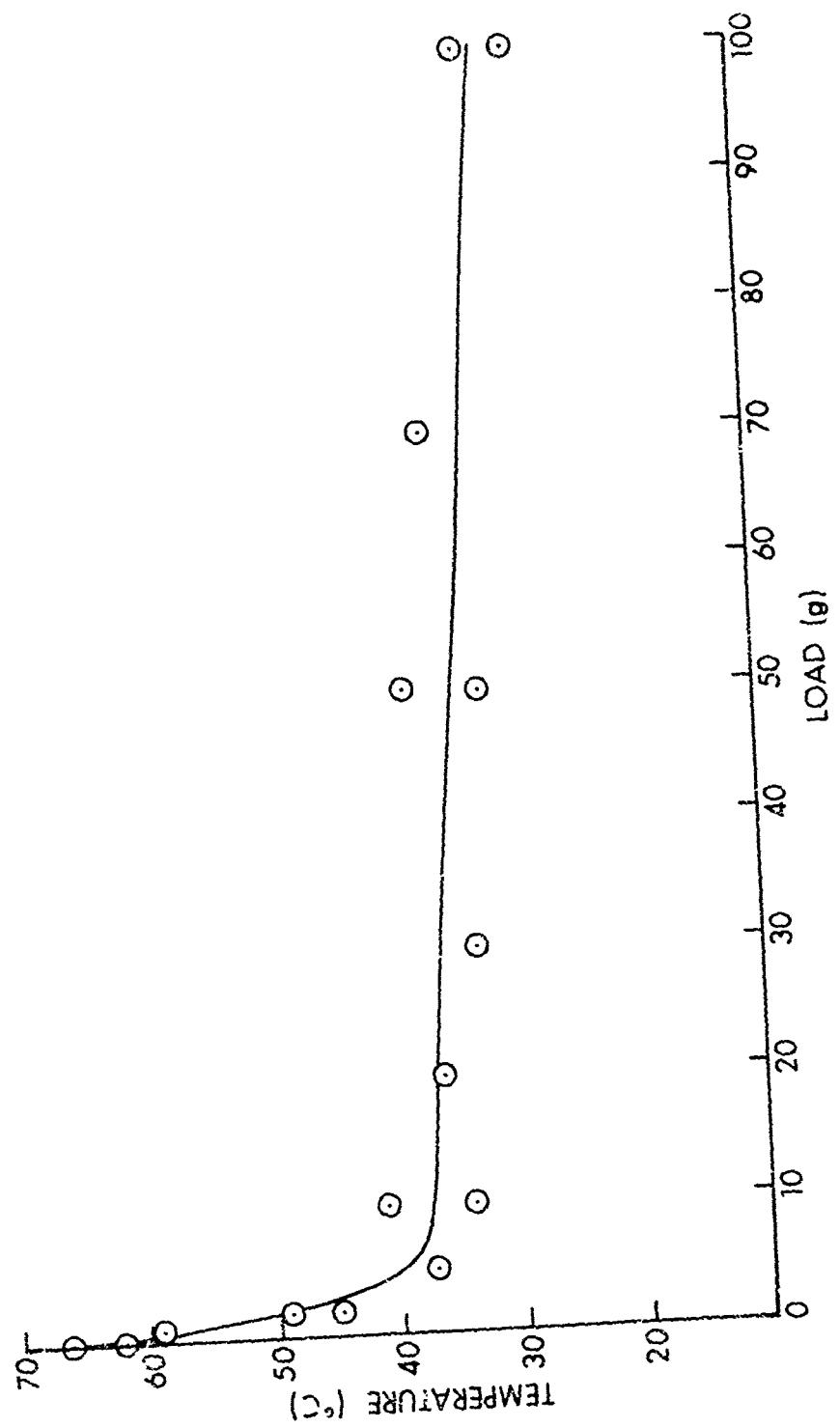


Figure 1. Penetration Temperature vs load for $\text{TiO}_2\text{-Wax}$

Hence, the endotherm seen in the DSC for the TiO₂ wax corresponds to softening of the wax and the softening occurs well below the maximum conditioning temperature.

These results clearly indicate that softening under load and thus the possibility of flow can occur for the TiO₂-wax additive at as little as 5K above room temperature. Storage or conditioning of additive-containing charges above room temperature could thus affect performance of the liner.

These results suggest substitution of a higher melting-wax that will not soften under an imposed load even when the wax is at the maximum propellant condition temperature. Recent tests by the Large Caliber Weapons System Laboratory with higher melting wax in the wear reducing liner demonstrated that no residue was left in the chamber⁵ firing rounds with the higher-melting wax.

Considering the high softening point of the polyurethane additive, no low temperature penetration under load effects were anticipated. This was surprisingly not the case, as the results of Table I indicate. However, Table I also indicates that duplicate load trials did not give reproducible results. This suggests that the penetration observed was not the result of a true softening under load which could lead to flow, but rather simply to a deformation of the polymer as a whole, with the deformation occurring at different temperatures depending on the local nature of the polyurethane surface where the load was placed.

TABLE I. LOAD VS PENETRATION TEMPERATURE FOR THE POLYURETHANE ADDITIVE

<u>Load, g</u>	<u>Penetration Temperature, K</u>
0	~ 473
2	526
20	305
50	539 316
100	377 304 302

⁵K. Russell and D. Downs, report in preparation.

IV. CONCLUSIONS

1. Thermomechanical analysis of the TiO_2 -wax blend in wear-reducing liners indicates the wax softens 40K below the melting point of 347K ($165^{\circ}F$). This is well below the maximum conditioning temperature of 336K ($145^{\circ}F$).

A wax required to be conditioned at 336K ($145^{\circ}F$) should have a melting point no lower than 383K ($230^{\circ}F$), as judged from the difference in melting temperature versus softening temperature under external load.

2. The polyurethane additive studied could be stored or conditioned at 472K ($390^{\circ}F$) or even slightly higher without impairing the effectiveness of the additive by flow under load.

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3. P. R. Grepps, "Component Development Test of Laminar Coolant, Barrel Wear-Reducing Additive in Cartridge, 105 mm Gun, M68, Ammunition Components", DPS Report No. 768, January 1963.
4. P. R. Grepps, "Development Tests of Laminar Cooling of Gun Bores, 90 mm, M41", DPS Report No. TW-417/6, June 1959.
5. K. Russell and D. Downs, report in preparation.

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